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Nuclear Security as a Multidisciplinary Field of Study

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What is Nuclear Security?

Nuclear security today is considerably more complex than it was during the Cold War. We enter the 21st century witnessing the global spread of advanced nuclear technology and a growing danger of nuclear proliferation, leading to an increasing likelihood that the world's most terrible weapons may be acquired by dangerous hands, including terrorist organizations. The specter of nuclear terrorism is of particular concern following the horrific events of September 11, 2001.

A world with a high degree of "nuclear security" would be one very different from the one we live in today. It would be one where the chance of nuclear weapons use by states or terrorists is much lower than it is today. It would one with greatly reduced risks that additional states would develop nuclear technology for military purposes and those that have already done so would be significantly reducing their reliance on such military applications. It would be a world that was confidently expanding its realization of the benefits of civil nuclear power.

More specifically, it would be a world in which all states possessing nuclear materials know to a high level of precision how much nuclear material they have, what form it is in, where it located, and whether it is adequately secured from theft or loss on a continuous, near-real-time basis. It would also be a world where all states had effective, enforceable laws criminalizing the unauthorized possession or trafficking of nuclear materials as well as possessing effective export and border controls to prevent illegal transfer of nuclear materials or the technologies and knowledge necessary for their production.

The need for understanding of today's evolving nuclear threats is critical to informing policy decisions and diplomacy that can move the world toward greater nuclear security. The scientific underpinnings for such an understanding are remarkably broad, ranging from nuclear physics and engineering to chemistry, metallurgy and materials science, risk assessment, large-scale computational techniques, modeling and simulation, and detector development, among others. These physical science disciplines must be combined with social science fields such as public policy, political science, international relations, international law, energy policies, economics, history, and regional studies in order to yield a deep understanding of today's nuclear security challenges. Together these areas constitute what this report terms *nuclear security science.*

In general, graduate and undergraduate program in nuclear security should accomplish these very basic goals:

- Provide the necessary fundamentals in nuclear security science from across the physical and social sciences.
- Provide an understanding of the unique challenges that arise when applying these fundamentals to specific real-world problems.
- Develop understanding of the need to balance the risks posed by nuclear technologies with their benefits.
- Include the opportunity for hands-on training (internships, lab experiments, simulation exercises)

This report describes on-going efforts to establish the multidisciplinary nature of nuclear security in the 21st Century and to develop education and training materials that are consistent with this view. The efforts are by nature international and cross-institutional. The report highlights the multidisciplinary nature of nuclear security, surveys the response to the critical need for educational and training initiatives in this area and suggests some additional activities that could be pursued.

Why is it Multidisciplinary?

The field of nuclear security lies at the intersection of technology and policy. Because it can be used for civilian or military purposes, nuclear energy from its inception has been controlled, regulated and protected by national and international legal authorities. It is therefore critical that nuclear security experts retain command of the body of national and international laws, regulations, conventions, treaties, guidelines and procedures that seek to safely and securely manage nuclear activities and prevent the spread of nuclear weapons.

Of course nuclear security experts must also understand the fundamental methods for measuring, controlling and accounting for nuclear materials, verifying activities at declared nuclear sites and searching for undeclared activities and illicit procurement networks. Nuclear security experts apply a variety of technologies and methodologies to accomplish these tasks including destructive and nondestructive assay of nuclear materials, containment and surveillance, unattended and remote monitoring, environmental sampling, nuclear forensics and information analysis. Furthermore, a nuclear security expert needs knowledge of the civilian nuclear fuel cycle and the basics of the nuclear weapons development process. The ability to grasp how the nuclear fuel cycle can be misused to support a weapons program, combined with knowledge of the policy and detection methodologies, give an individual the skills to design and evaluate effective nuclear security and safeguards systems and to identify policy and technology gaps for future research and development.

As mentioned, these technical skills should be complimented with basic knowledge of the historical, legal and political aspects of nuclear security and nonproliferation. This background is vital to knowing the policy context that often determines key parameters of appropriate technical solutions. High quality policy analyses and system studies in these areas are vital to understanding future trends in nuclear proliferation threats and using that understanding to develop effective responses to these threats. This body of knowledge includes but is not limited to the following:

- The Treaty on the Nonproliferation of Nuclear Weapons (NPT)
- Nuclear Weapon-Free Zones
- International Atomic Energy Agency (IAEA) statutes
    - INFCIRC153, 66, and 540 (the additional protocol)
- U.S. legal obligations on nuclear fuel materials
- Physical Protection Convention
- State level laws and regulations on nuclear activities
- The Proliferation Security Initiative
- Positive and Negative Security Assurances
- Nuclear Supplier Group and other nuclear and dual-use export controls
- Fissile Material Cut-Off Treaty
- Restrictions on Nuclear Testing (CTB, others)
- Euratom and ABACC safeguards arrangements
- UN Security Council Resolution 1540 and the Anti-Terrorism Convention

- Proposals by President Bush and IAEA Director El Baradei on nuclear user-supplier arrangements
- New IAEA BOG Committee on Safeguards and Verification

These elements of governance are constantly evolving and are largely the result of political and economic forces within and between countries. Another important body of knowledge that would be valuable for nuclear security experts to have fundamental understanding of is the set of treaties and agreements that impose quantitative and qualitative limits on nuclear weapons and materials in military programs. If the trend towards smaller stockpiles of weapons and greater control on military fissile materials continues this component of nuclear security will become increasingly important.

Why is Nuclear Security Training So Important Now?

Recently several factors have converged to create an impending organizational, human resource, knowledge management and technical capability crisis in all areas of nuclear security science. Nuclear engineering, chemistry and related fields of study the United States and Europe have been in decline for more than twenty years due in part to the stagnation of the nuclear energy industry following accidents at Three Mile Island and Chernobyl. In addition, the generation of nuclear energy specialists that spent their careers during the early surge of the nuclear power industry and the Cold War nuclear arms build-up are now retiring. These trends are reducing the availability of skilled labor at a time of rapidly increasing need in the field of nuclear security due to a projected growth in the global nuclear energy industry, rising concern regarding the risks of nuclear weapons proliferation and nuclear terrorism and rapidly evolving technology.

Over the next five years some 50 percent of the IAEA's top inspectors and senior managers are expected to retire, taking with them key institutional knowledge and technical skills. The simultaneous expansion and evolution of the IAEA mission related to implementing the Additional Protocol, efforts to combat illicit nuclear trade and a potential new safeguards agreement with India highlights the shortfall in needed personnel. In addition, the expertise needed for missions such as determining the origin of nuclear materials used by smugglers or nuclear terrorists is dwindling.[1]

An expansion of nuclear energy use worldwide will sharply expand the need for nuclear safeguards specialists in at least three categories; national nuclear facility regulators, commercial plant operators and safeguards inspectors at the IAEA. Without significant new investment by all of these organizations in the human, institutional and technical capital of safeguards, it is unlikely that the challenge of preventing a rise in global nuclear energy use from causing a corresponding increase in the risks of nuclear proliferation, nuclear terrorism and illicit nuclear trade will be met.

Yet the growth of the nuclear energy industry is real. At the end of 2006, twenty-seven nuclear power units were under construction with a total generating capacity of about 22 Gigiwatts (GWe). Twenty additional countries have taken action to implement nuclear power between 2015 and 2030. Among this group—Algeria, Morocco, Tunisia, Libya, Egypt, Turkey, Jordan, Saudi Arabia, and Yemen— are located in the war-torn region of the Middle East. Morocco, Tunisia, Jordan, and Yemen seem unlikely to achieve their stated goal. But the others, with U.S., Chinese, French and Russian nuclear cooperation, may well succeed. The nuclear expertise needed to safely operate and safeguard nuclear industries in these countries alone would be extensive.

The United States is leading the Global Nuclear Energy Partnership (GNEP) to promote increased use of nuclear energy. However the pace of nuclear energy expansion could also be constrained by the shortage of nuclear expertise.[2] This would limit the potential contribution that nuclear energy could make to mitigating atmospheric pollution.

[1] See Jon Fox, "Dwindling Scientific Expertise Threatens U.S. Nuclear Forensics," *Global Security Newswire*, Oct. 11 2007, http://www.nti.org/d_newswire/issues/2007_10_11.html and Elizabeth M. Fowler, "Careers; A Shortage of Nuclear Chemists," *New York Times*, August 29, 1989. http://query.nytimes.com/gst/fullpage.html?res=950DE6D61538F93AA1575BC0A96F948260&sec=&spon=&pagewanted=print

[2] Murphy, Marina, "Skills shortage could thwart nuclear plans." *Chemistry and Industry*, January 28, 2008.

What is Being Done?

Already there is significant action from government, industry and academia to address the shortfall in human resources in the nuclear field. One encouraging development was the significantly increased support and consensus for nonproliferation education expressed by all parties of the NPT at the 2007 NPT Preparatory Committee meeting.[3] Other key efforts include the focus given to the issue by the Institute of Nuclear Materials Management (INMM) with the inclusion of a session on Nuclear Safeguards Education and Training at its 8th International Conference on Facility Operations-Safeguards Interface in April 2008 being only the most recent of a series of INMM panels and committees devoted to the subject. U.S. Federal Agencies including NNSA, the Defense Threat Reduction Agency (DTRA) and the Department of Homeland Security have all initiated partnership programs with various Universities to fund educational activities across a broad range of nuclear security sciences. In addition, the U.S. National Science Foundation supported dozens of major graduate and post-graduate scholarships in the nuclear security field through its Public Policy and Nuclear Threats program.

Notable in this area is the support being provided by NNSA's Office of Nonproliferation and International Security (NA-24) through its Next Generation Safeguards Initiative (NGSI). Among other activities the NGSI will support education and training programs at the national laboratories in partnership with the Nuclear Security Science and Policy Institute at Texas A&M University, the Center for Nonproliferation Studies at the Monterey Institute of International Studies and other universities. At the same time an increasing number of U.S. universities are responding to the need for nuclear security specialists through these government collaborations and with their own new certificate and degree programs. Several of these explicitly define nuclear security and nonproliferation as multidisciplinary and utilize various academic departments to offer integrated nuclear security curriculum. These include but are not limited to Texas A&M

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[3] Remarks by William Potter at the CNS Seminar "The 2007 NPT PrepCom: Making the Best of a Bad Situation." June 4, 2007.

University, University of Missouri, Georgetown University, Ohio State University, University of Washington and Washington State.

University-Industry Partnerships are also increasing. One example is the World Nuclear University Working Group on Safeguards and Security Education and Training. World Nuclear University is supported by the World Association of Nuclear Operators and the World Nuclear Association. The IAEA's Office of Nuclear Security is also developing graduate curriculum for the full range of nuclear security activities and the European Safeguards Research and Development Association (ESARDA) has established a Training and Knowledge Management Working Group.[4]

Finally, the academic and research community has responded to the need for new training texts and reference materials. The sources listed below are a small sampling of recent scholarly literature in the area of nuclear security:

- Matt Bunn and Anthony Weir, *Securing the Bomb,* Annual Volume available from the Nuclear Threat Initiative http://www.nti.org/e_research/cnwm/overview/cnwm_home.asp
- Dave Hafemeister, *Physics of Societal Issues,* Springer 2007
- National Academy of Sciences, *Monitoring Nuclear Weapons & Nuclear-Explosive Materials,* Committee on International Security and Arms Control, April 2005
- James E. Doyle et al., *Nuclear Safeguards, Security and Nonproliferation,* Elsevier Science and Technology, June 2008 http://www.elsevier.com/wps/find/bookdescription.cws_home/714662/description#
- *Handbook of Nuclear Engineering*, Springer Scientific, forthcoming 2009

What Additional Actions Could Be Taken?

The fundamentals of nuclear security science can be taught at university level. These programs can be greatly improved through formal or informal integration with official government or IAEA nuclear safeguards training curriculum. Mechanisms for achieving this integration are University-National Laboratory collaborations, fellowships that

[4] G. Janssens-Maenhout1, L.-V. Bril, W. Janssens, "International Academic Education on Nuclear Safeguards," ESARDA BULLETIN, No. 35

provide opportunities for temporary rotation of nuclear security experts and faculty between academia, industry and government, and guest lecture programs that expose students to the challenges of implementing nuclear security policies and technologies. Potential mechanisms for this include training held at the laboratories to educate university faculty and exchange programs for laboratory individuals to take "sabbaticals" to universities to teach and interact with both students and faculty.

The challenges that Universities face in creating these programs include lack of financial support, uncertainty regarding the ability to attract enough students for such specialized programs and a limited number of faculty with the needed interest, training and experience. Maintaining adequate laboratory resources and even access to nuclear research facilities are other challenges to offering a well-rounded concentration on nuclear security. Other interested stakeholders could help universities overcome these challenges and, in turn establish relationships with universities that improve the skill level and value of students entering the workplace after completing programs that focus on nuclear security. Some examples of collaborative activities that could improve nuclear security education include:

- Consumers of nuclear security training such as government agencies, academia, industry and the IAEA should forecast their anticipated workforce needs.
- They should also provide leave opportunities and financial support for early and mid-career staff to attend appropriate university programs.
- Universities should seek out guest lecturers and temporary faculty from among experienced nuclear security professionals, who in turn should be encouraged by their organizations to perform such activities.
- Government agencies and universities should interface with nuclear industry groups to address the issue of human capital loss. These groups include the Energy Facility Contractors Group (EFCOG), the INMM, Institute of Nuclear Power Reactor Operators (INPRO), World Nuclear Association, and the Nuclear Energy Institute

Nuclear security experience has traditionally been gained through on-the-job and ad-hoc training by governments, commercial nuclear operators or the International Atomic Energy Agency (IAEA). Creating such opportunities for students and early career professionals will be critical to sustaining adequate numbers of technically trained individuals to meet the future needs of government and industry worldwide.

Another important thrust for improving nuclear security training over time is to maintain robust research and development programs. This can only be done by governments, and in ideal situations, with some contribution by industry. A robust nuclear security R&D program offers another activity that provides valuable input to training programs and creates opportunities for students who can rotate through such programs at the national laboratories as part of their nuclear security internships. In the field of nuclear security some general areas that could provide opportunities for involving student include:

- Addressing the complexities of new materials that are expected to be used in future nuclear fuel cycles such as fuels for advanced burner reactors and the products of advanced reprocessing technologies.
- Extending the growing field of information barrier technology, as applied to nuclear transparency initiatives. This will require a cadre of experts having a more intimate knowledge of computer science, cryptography, hash algorithms, and authentication schemes.
- Developing advanced simulation tools for nuclear security requiring expertise with the latest simulation software.
- Applying advanced visualization for detection of anomalies that could signal attempts for nuclear material diversion or nuclear trafficking.
- Develop "network" science and technology encompassing self organizing, autonomous systems able to process disparate data, to recognize normal and off-normal "patterns", etc. applicable to future nuclear safeguards and nuclear materials tracking systems.

Finally, it could be beneficial to establish some "grand challenges" for nuclear security to help organize and motivate the development of nuclear security as a multidisciplinary field of study. Candidates for such challenges chosen at random from a broad range of possibilities include:

- Can efficient civilian nuclear fuels cycles be created in which there is no presence of directly weapons-usable nuclear materials?
- How can we truly meet quantity and timeliness goals for materials accountancy at large throughput nuclear facilities?
- How can undeclared nuclear activities be detected and countered?
- What are the political, technical and institutional requirements for the elimination of nuclear weapons?
- How can we increase the probability of detection of illicit trafficking in nuclear materials and technology?

In summary, a strong cadre of nuclear security experts gives the United States a major advantage in its ability to assist and therefore influence the international nuclear order. This is critical for national and international security. The synergy between excellence in policy and systems studies and the quality of technology and technical expertise needs to be acknowledged and maintained as one of the nations' core nuclear security capabilities.